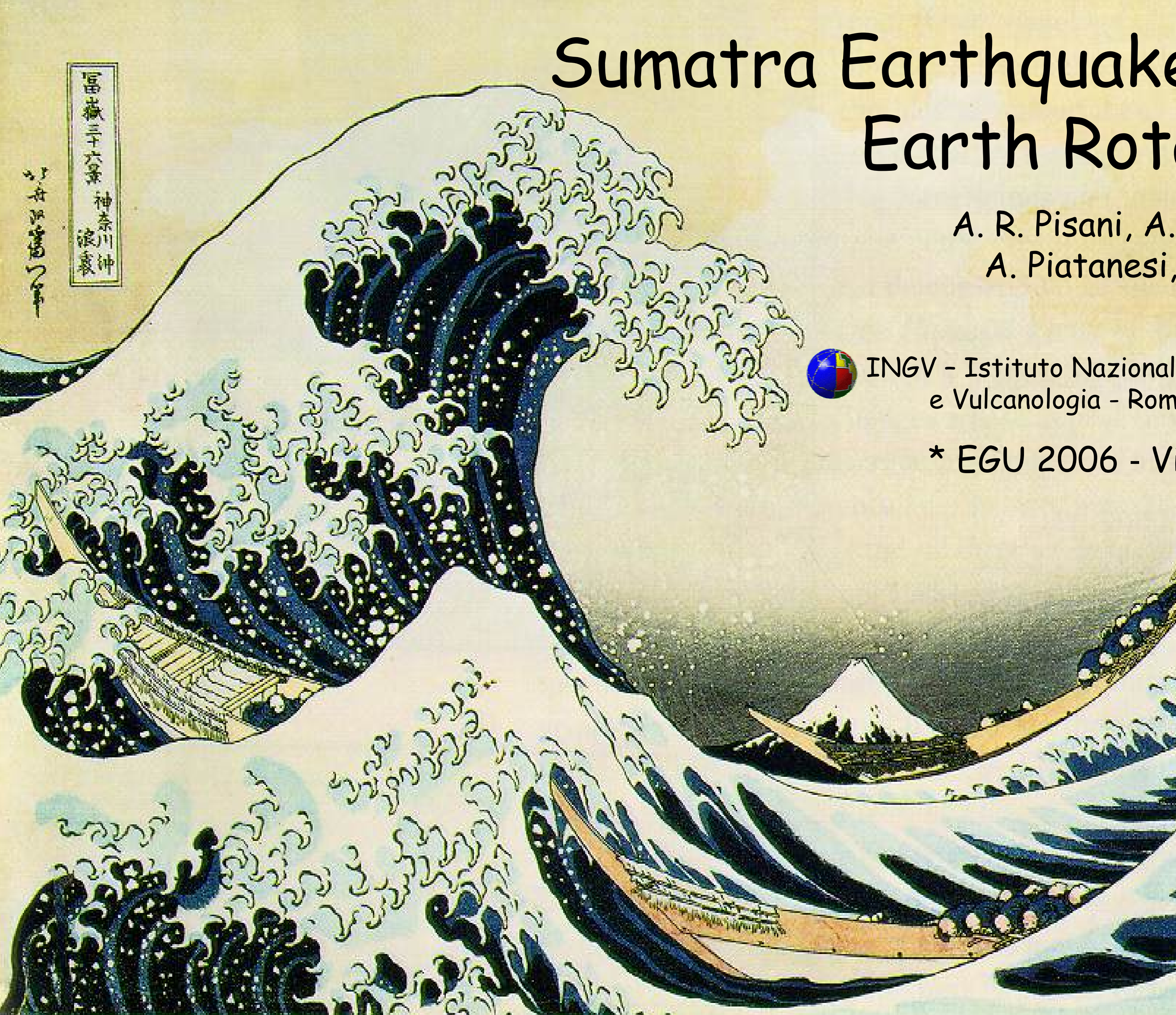

Sumatra Earthquake [illegible]and Earth Rot[illegible]ion

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* EGU 2006 - Vie[illegible]a *

On 26th December 2004 off the west coast of northern Sumatra occurred one of the most devastating earthquakes of the modern history.

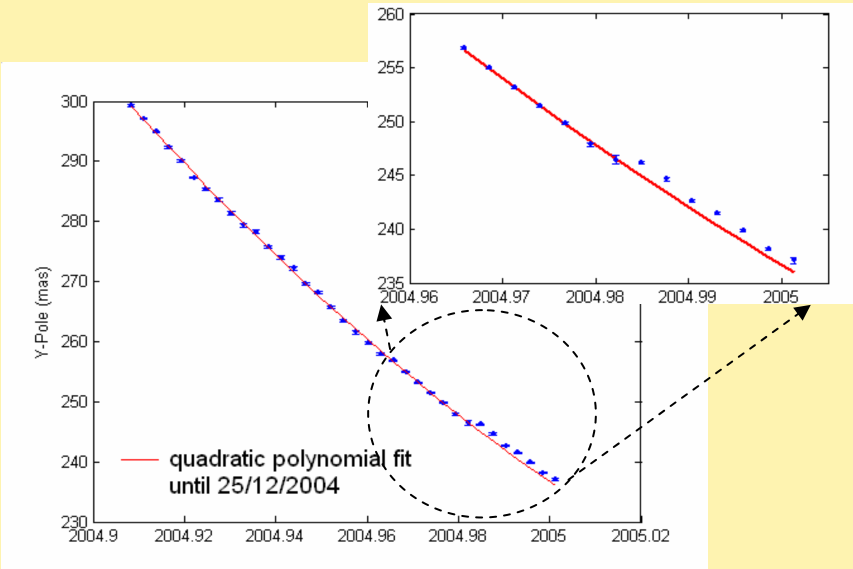
In correspondence of the event, a step discontinuity in the instantaneous rotational pole path has been evidenced by means of SLR and GPS techniques.

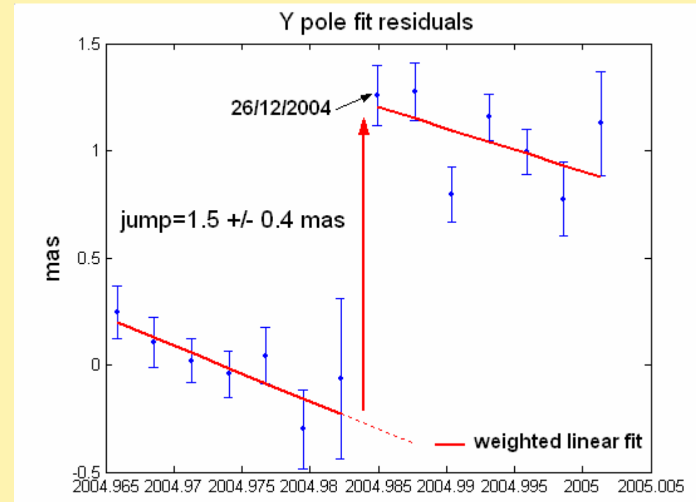
- Sumatra is probably the largest event since the giant Chile earthquake (1960).
- There has been a great improvement of the accuracy in the pole position detecting techniques since 1960.

Sumatra earthquake seems to be the best candidate to study the effects given by a seismic event on polar motion.

Geodetic evidences of the step discontinuity in the pole path.

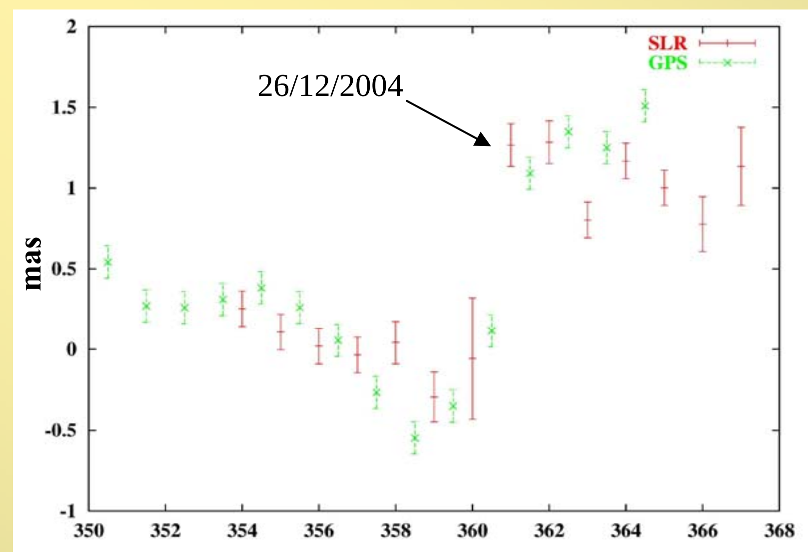
On 19th January 2005 the International Laser Ranging Service (ILRS) provided preliminary estimates about the earthquake effect on pole motion.





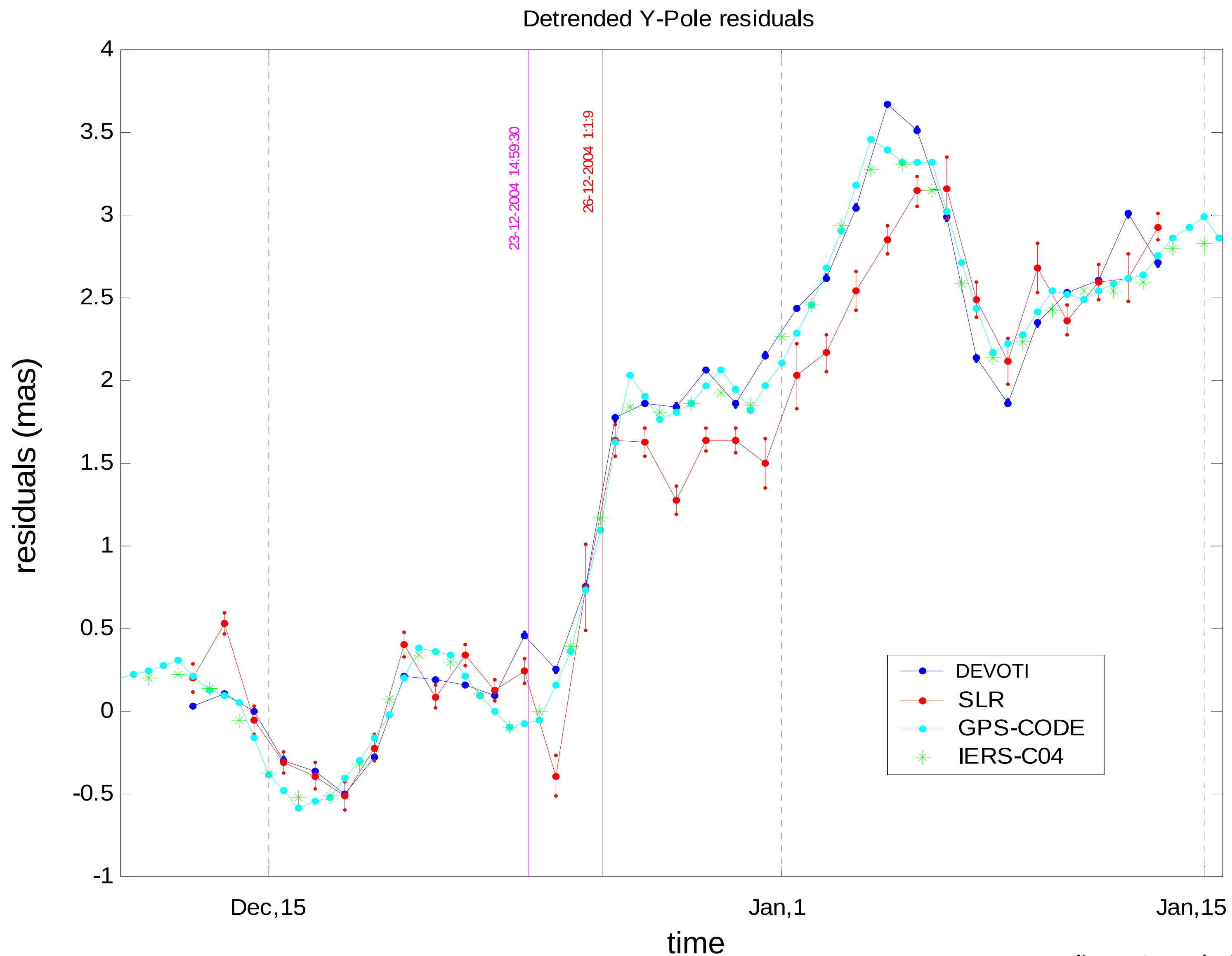
(Bianco, Luceri, Sciarretta 12/2004)

These estimations, based on SLR technique and then compared with GPS data, revealed a step discontinuity of about 1.5-2.0 mas in the y-component of the instantaneous rotational pole in correspondence of Sumatra earthquake.



(Hugentobler 01/2005)

A more recent study (09/2005) shows that independent solutions, retrieved by means different techniques, give a coherent measure of the y-pole displacement during the Sumatra event.



(Devoti et al. 09/2005)

Did the earthquake cause the jump in the pole path?

A permanent dislocation given by an earthquake is characterized by an excitation function of the form:

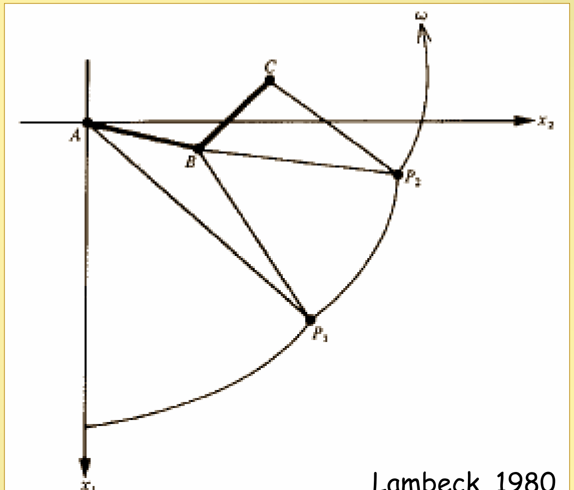
$$\boldsymbol{\Psi}(t) = \boldsymbol{\Delta\Psi} H(t)$$

where $H(t)$ is the Heaviside step function and

$\boldsymbol{\Delta\Psi}$ is the magnitude of the excitation.

If the perturbation has a *step-like temporal dependence*:

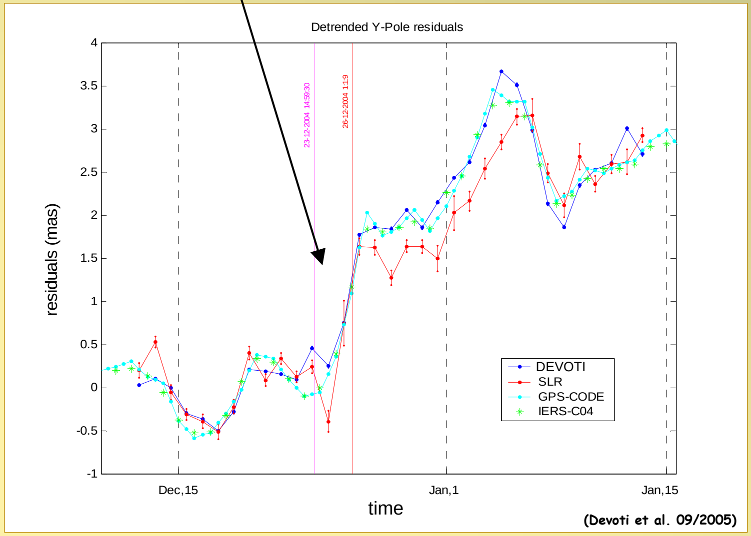
the resulting pole path is a continuous curve with a sudden change in the curvature radius when the perturbation is turned on.



Lambeck, 1980

What did cause the step-like discontinuity in the pole path?

❖ The jump in the instantaneous rotation pole path is compatible with an excitation function characterized by a delta-like temporal dependence which is produced by a transient *mass redistribution.*



We want to test the hypothesis that the perturbation to the inertia tensor, which produced such discontinuity in the pole path, has been caused by the

transient water mass redistribution produced by the TSUNAMI.

To evaluate the discontinuity in the pole path produced by the tsunami we have to solve the instantaneous rotational pole motion equation:

$$\mathbf{m}(t) = m_x(t) + j m_y(t) = -j\sigma_0 \frac{k_0}{k_2 - k_0} e^{j\sigma_0 t} \int_t \mathbf{\Psi}_{tsunami}(\tau) e^{-j\sigma_0 \tau} d\tau$$

σ_0 = Chandler frequency;

$\frac{k_0}{k_0 - k_2}$ = correction given by the elastic deformation of the rotational Earth;

$\mathbf{\Psi}_{tsunami}$ is the *excitation function* that includes the *perturbation associated to the mass redistribution* given by the TSUNAMI and its form is:

$$\mathbf{\Psi}_{tsunami} = \mathbf{\Psi}_{\mathbf{m}} + \mathbf{\Psi}_{\mathbf{v}}$$

Mass term

associated to the static redistribution of mass caused by the variation of sea surface.

Velocity term

associated to the exchange of angular momentum between the Earth and the horizontal flowing water.

To evaluate the instantaneous rotational pole motion $\mathbf{m}(t)$ first of all we need to calculate the excitation function associated with the tsunami:

$$\boxed{\boldsymbol{\Psi}_{tsunami} = \boldsymbol{\Psi}_{\mathbf{m}} + \boldsymbol{\Psi}_{\mathbf{v}}}$$

Mass Term: vertical water dispacement.

Velocity Term: horizontal velocity field.

$$\begin{cases} \boldsymbol{\Psi}_{\mathbf{m}x} = -\int\limits_{V_w} \dfrac{\rho_w}{C-A} r^2 \cos\phi \sin\phi \cos\lambda \, dV \\ \boldsymbol{\Psi}_{\mathbf{m}y} = -\int\limits_{V_w} \dfrac{\rho_w}{C-A} r^2 \cos\phi \sin\phi \sin\lambda \, dV \end{cases}$$

$$\begin{cases} \boldsymbol{\Psi}_{\mathbf{v}x} = -\int\limits_{V_w} \dfrac{2\rho_w}{\Omega(C-A)} r \sin\phi \left(u_\lambda \cos\lambda - u_\phi \sin\phi \sin\lambda\right) dV \\ \boldsymbol{\Psi}_{\mathbf{v}y} = +\int\limits_{V_w} \dfrac{2\rho_w}{\Omega(C-A)} r \sin\phi \left(-u_\lambda \sin\lambda - u_\phi \sin\phi \cos\lambda\right) dV \end{cases}$$

ϕ, λ Latitude and longitude.

u_ϕ, u_λ Horizontal Velocity Components.

$A,\ C, \Omega$ Equatorial and polar inertia momentum, angular velocity of the Earth.

ρ_w Oceanic water density.

$\boldsymbol{\Psi}_{\mathbf{m}}, \boldsymbol{\Psi}_{\mathbf{v}}$ have been evaluated using a *synthetic numerical tsunami model* which gives:

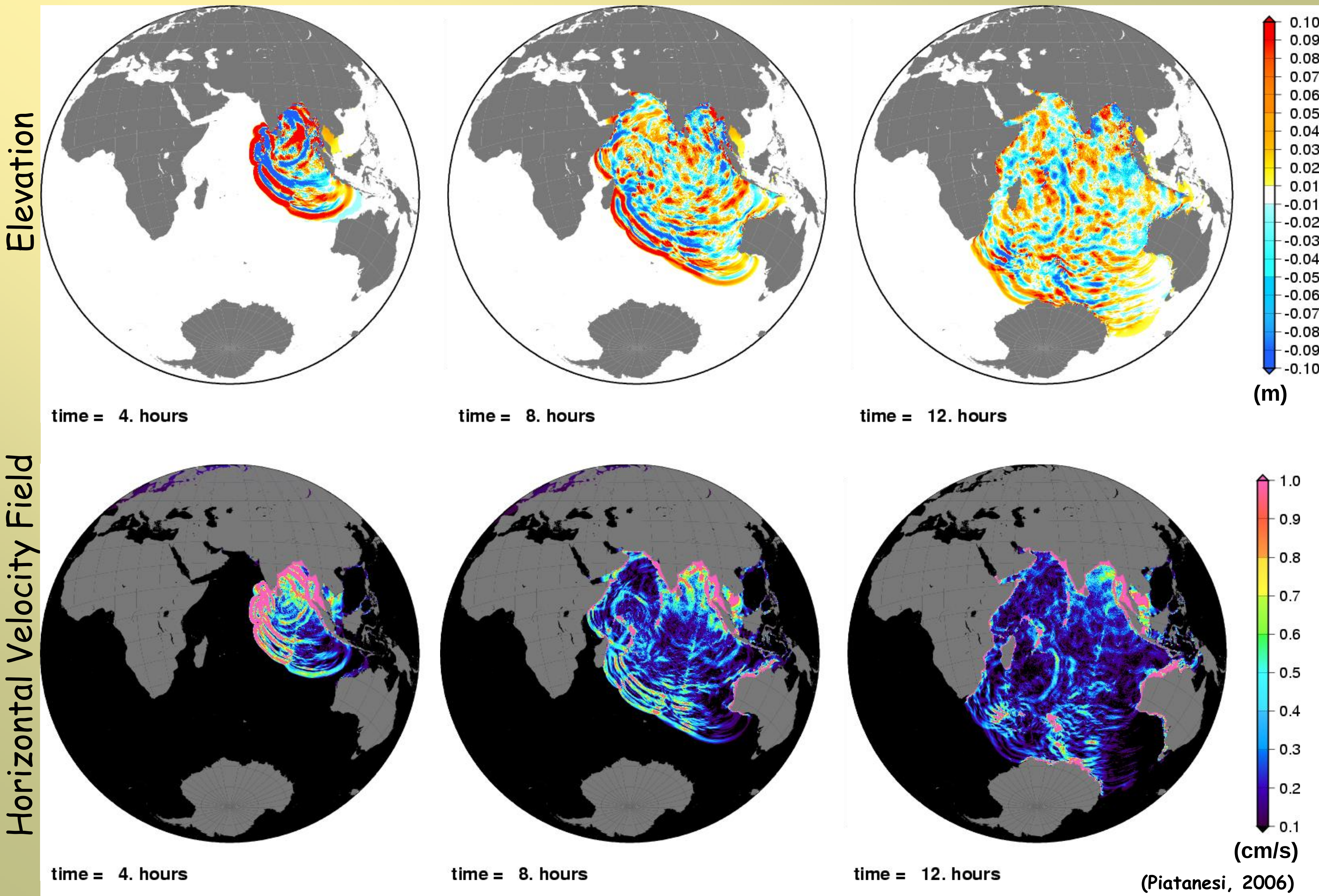
*Vertical displacement of the water

*Horizontal velocity field

in the propagation area of the tsunami, in a time window of 16 hours.

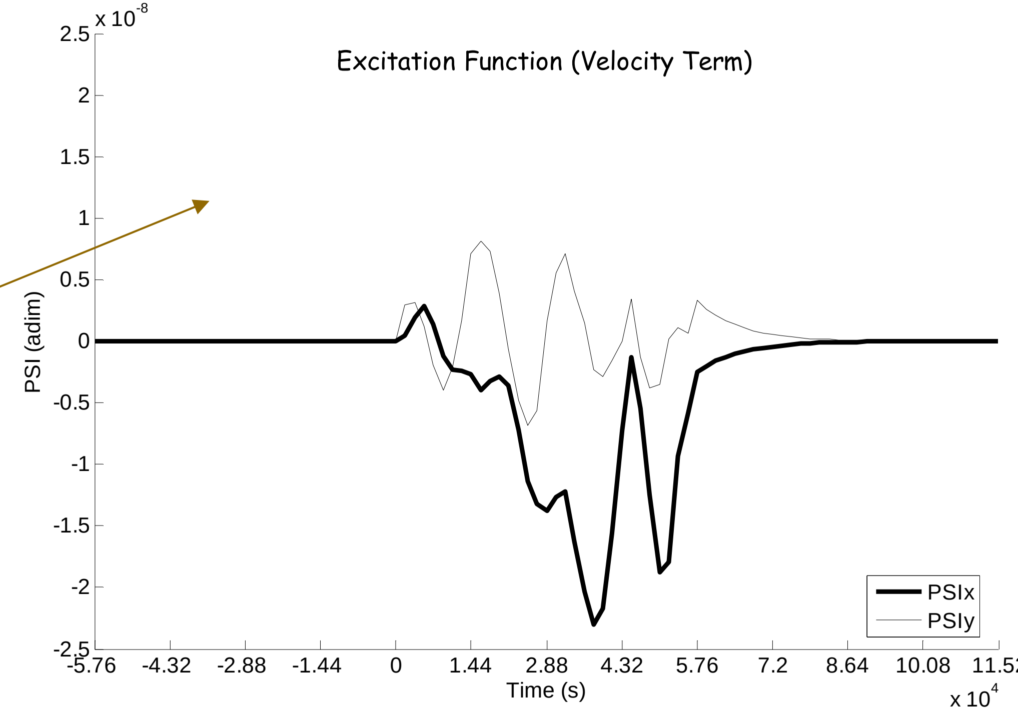
(An area of about 10^8 Km^2 ($-75° < \phi < 30°$ and $0° < \lambda < 150°$) sampled into a grid of 2′)

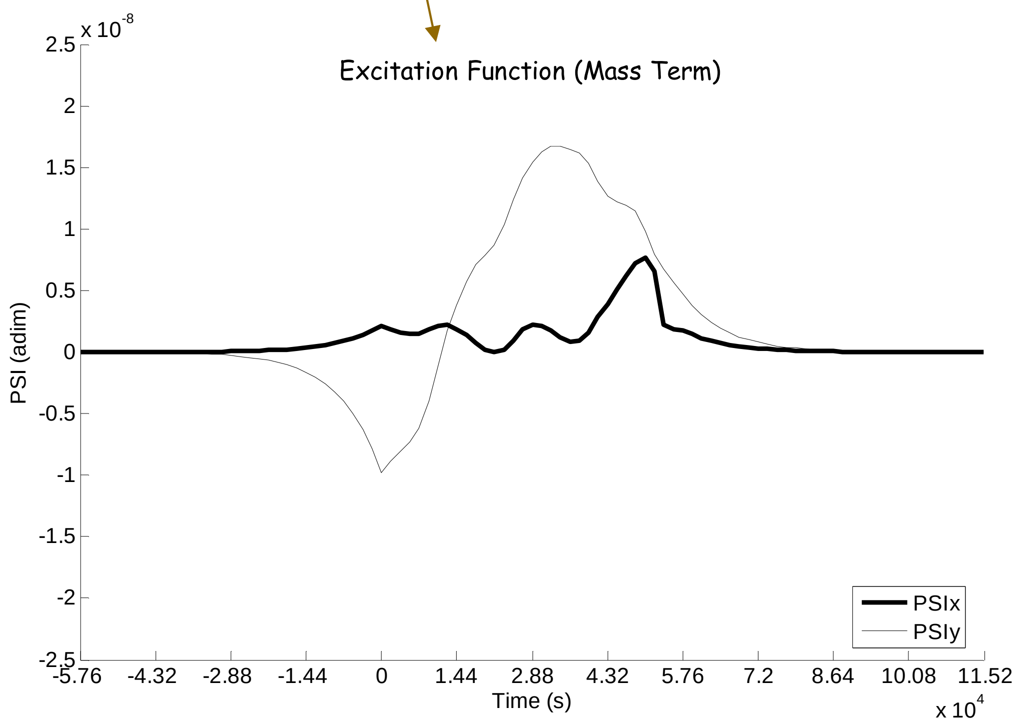
Snapshots of the tsunami propagation from the numerical model at different time steps.



From the synthetic numerical tsunami model:

$$\Psi_{tsunami} = \Psi_{\mathbf{m}} + \Psi_{\mathbf{v}}$$



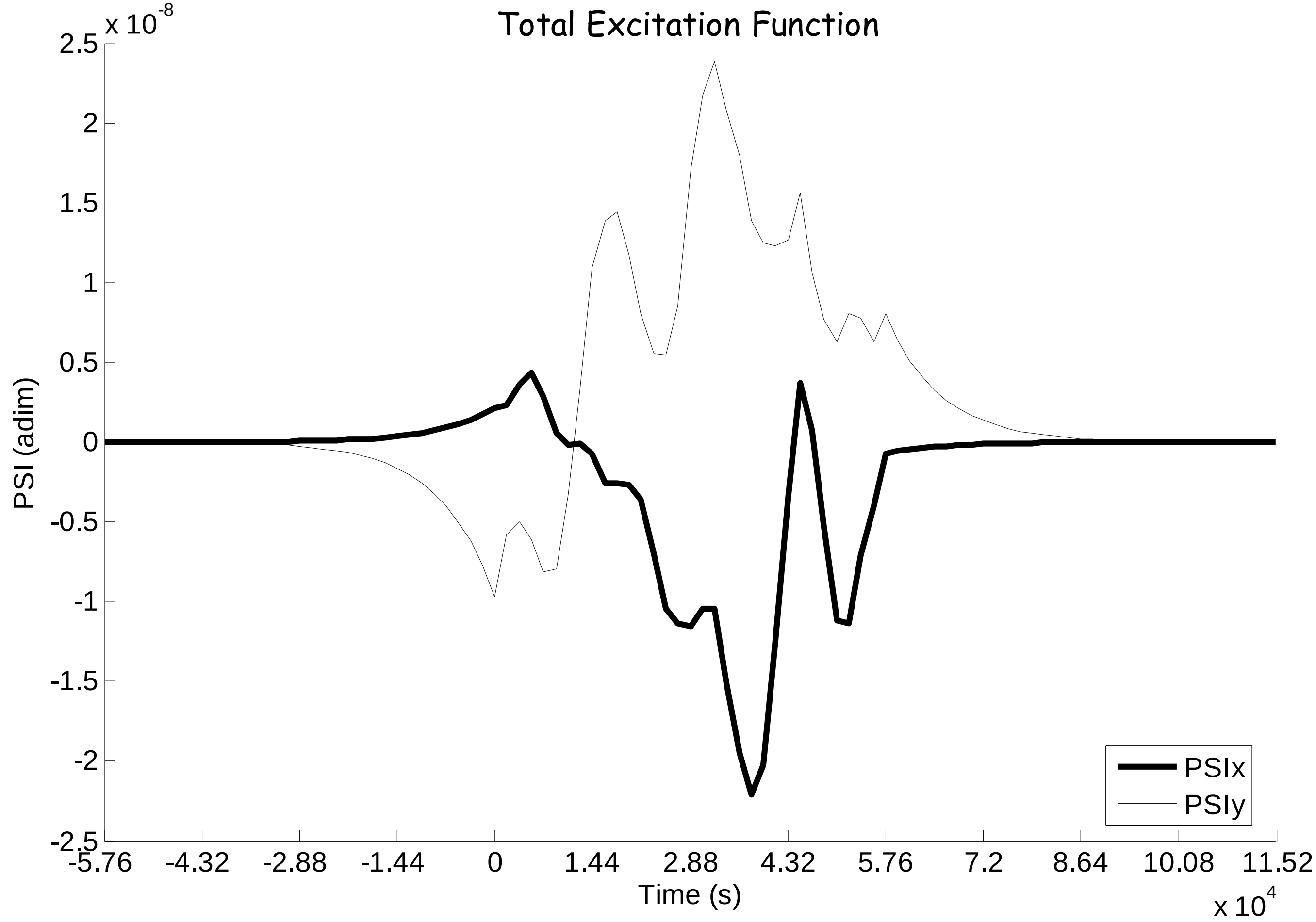


Trends of the two different contributions given to the total excitation function by the *mass term* and the *velocity term*.

Total excitation function.

$$\Psi_{tsunami} = \Psi_{\mathbf{m}} + \Psi_{\mathbf{v}}$$

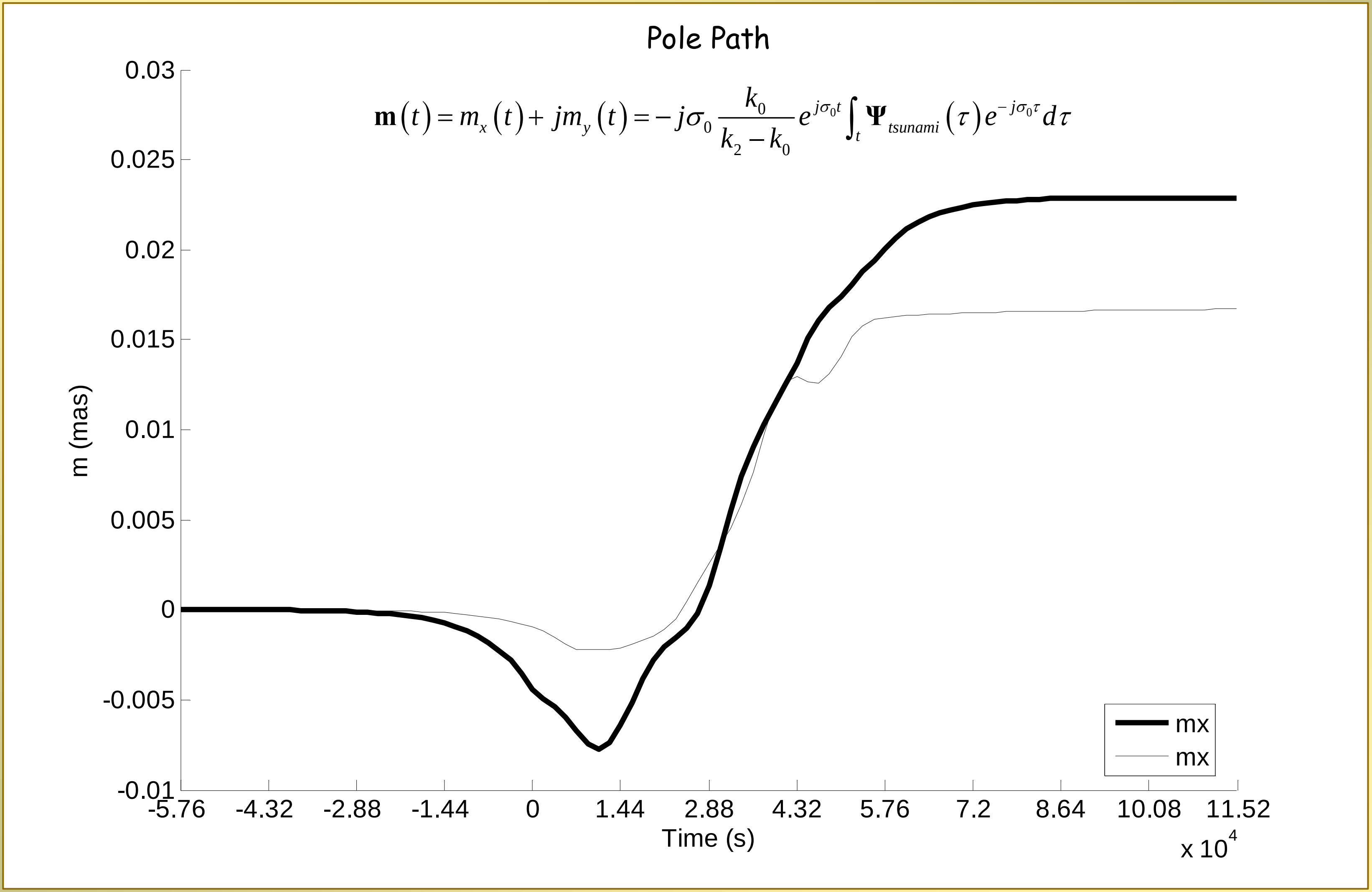
(Excitation pole or mean pole of rotation around which revolves the instantaneous rotational pole)



A delta-like temporal dependence that we were looking for obtain the observed pole path displacement.

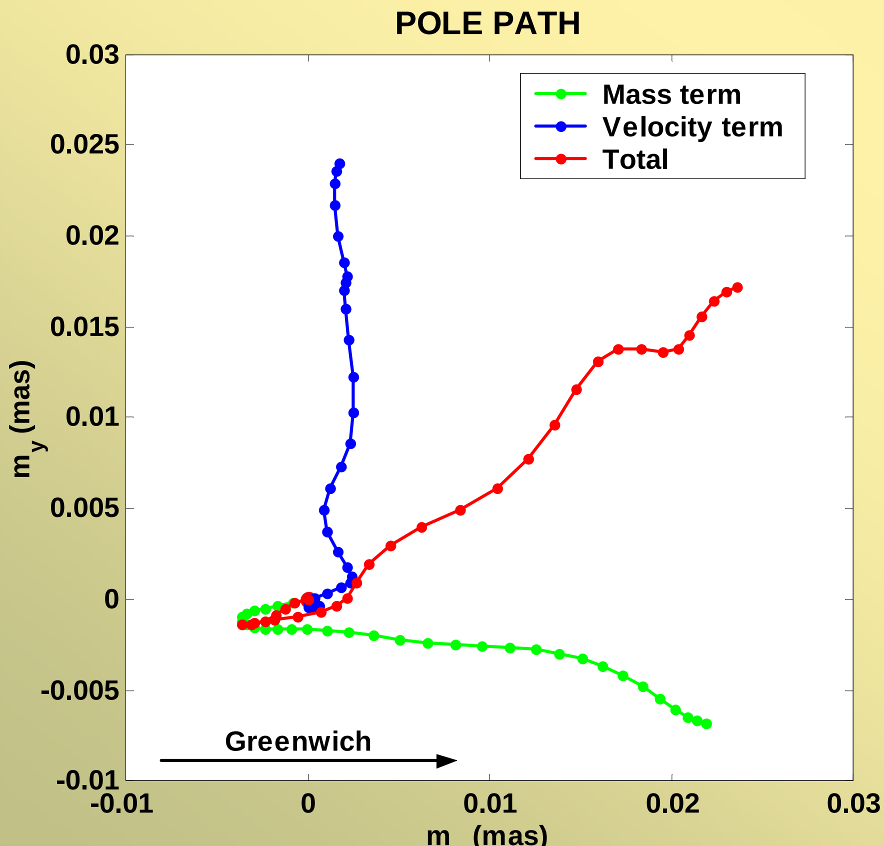
Solving the instantaneous rotational pole motion equation we obtained

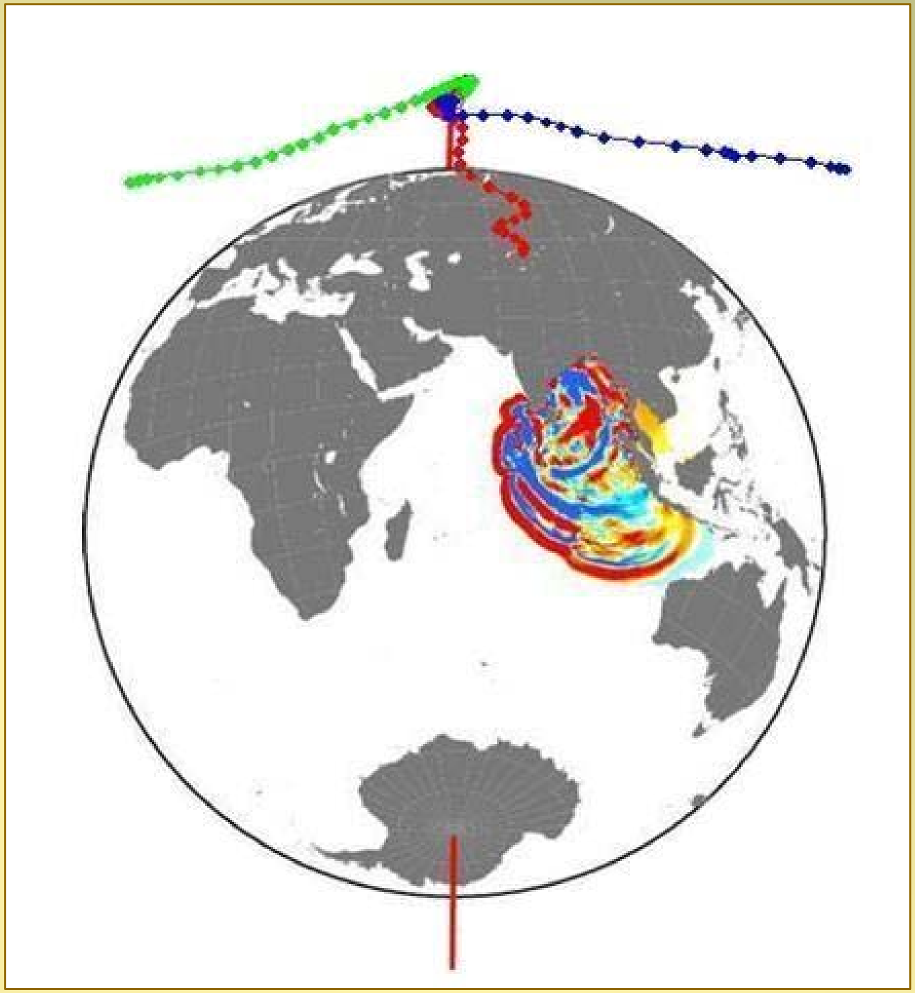
Pole path variations associated with the excitation function $\mathbf{\Psi}_{tsunami}$



❖ Shift in the pole path from
- our simulations: ~ $3.3 \cdot 10^{-2}$ mas
- geodetic techniques: ~ (1.5 - 2.0) mas

Pole path after the occurrence of the Tsunami.





Pole paths overlapped to the planisphere.

(Devoti 2006)

Summary

- Geodetic data evidenced a discontinuity in the y-component of the istantaneous rotational pole path in correspondence of Sumatra earthquake.

- We assumed that such discontinuity has been caused by a perturbation to the inertia tensor associated with the mass redistribution due to the tsunami.

- The total excitation function and the perturbation to the pole path, have been obtained using a synthetic numerical tsunami model that gave us:
  - excitation function values due to the vertical displacement of the water;
  - excitation function values due to the horizontal velocity field of the flowing water.

- Finally, our simulations show:

  ✓ the simulated shift in the pole path is 50 times smaller than that observed in geodetic data;

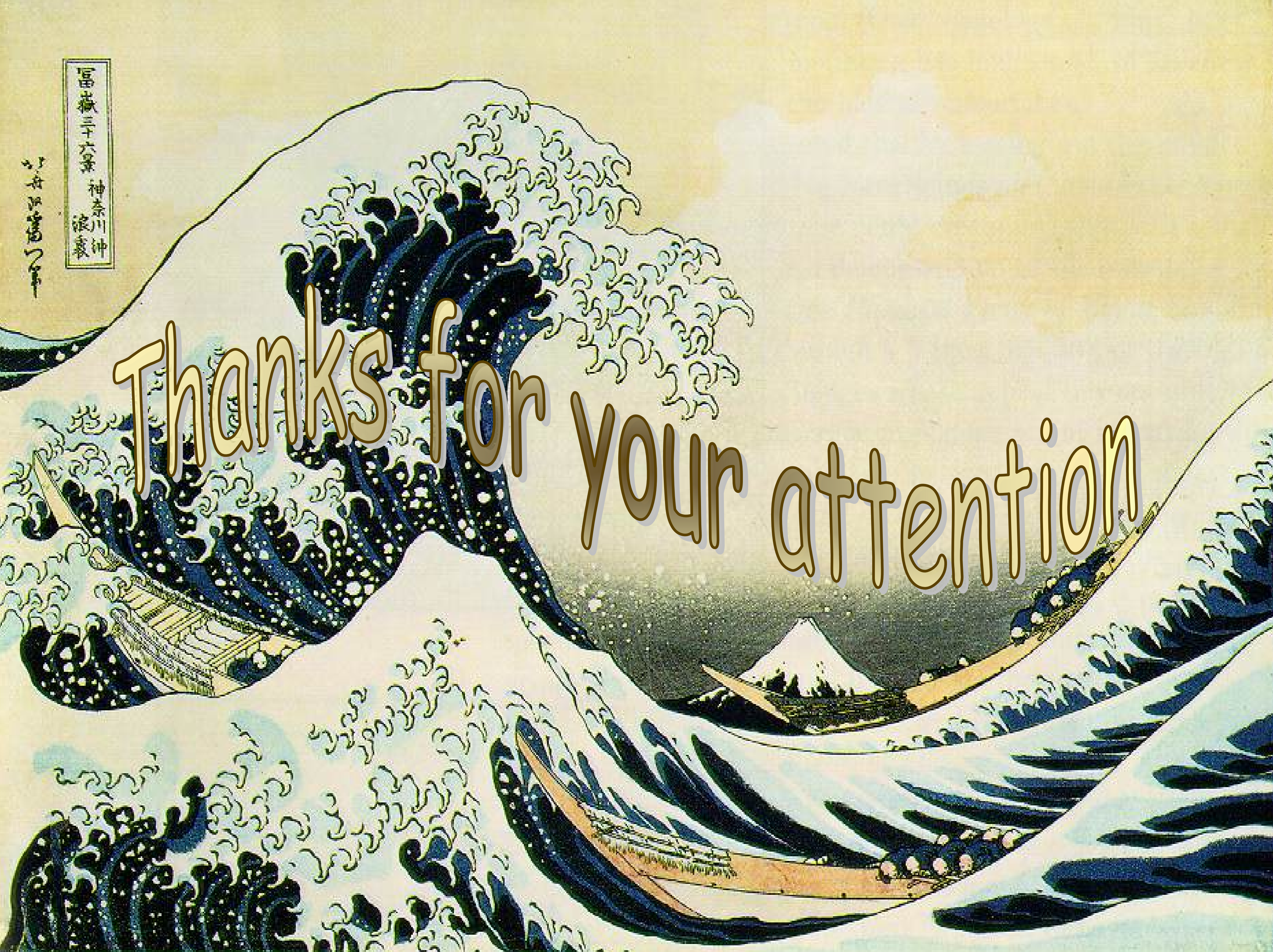
⇨ ***Shift in the pole path is not due to the mass redistribution caused by the tsunami.***

❖ Nevertheless, the results of our analysis cannot be considered conclusive for three main reasons:

1. Dragging effects could play an important role in exchanging angular momentum between Ocean and solid Earth during the propagation of the tsunami wave.
   Presently we are not able to include this effects in our numerical simulations.

2. We observed an increase of perturbation in correspondence of an increase of resolution of the grid used to sample the propagation area. (This is probably due to dispersion artefacts in the computed wavefield strongly dependent from the domain resolution). Two arc minutes is now the maximum resolution affordable by our numerical routines, but it is possible that further increase in the resolution would result in an increase in the computed perturbation too.

3. The elevation of a tsunami wave has been subject to several investigations and also experimental observations, for this reason while we can consider the output of the simulations, concern with water elevations, highly reliable, this is not true for the output of the simulations concern with the velocity field of the horizontal flow.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Thanks for your attention